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A SEMI-TRANSPARENT POWER MONITOR INTEGRATED WITH A LIGHT PRODUCING MODULE

This is a continuation-in-part of U.S. Serial No. 09/469,122 filed December 21, 1999 entitled AMORPHOUS SILICON SENSOR WITH MICRO-SPRING INTERCONNECTS FOR ACHIEVING HIGH UNIFORMITY IN INTEGRATED LIGHT-EMITTING SOURCES.

Background of the Invention

This invention relates to the transmission of data via optical devices, and the monitoring of those devices using sensors.

There is ongoing pressure to increase the speed at which data is transmitted, which in turn is driving the demand for high bandwidth fiber optics components. In these systems, it is often necessary to monitor the light output of the components. Normally, part of the light is diverted to a monitor photodiode – a process that leads to high insertion loss and complicated packaging.

One particular type of optical component uses infrared vertical cavity surface-emitting lasers (VCSEL). While the following discussion focuses on VCSEL-based optical transmission devices, it is understood that other light producing modules may equally employ the described concepts. In existing VCSEL-based optical transmitter packages, a photo-diode is used to monitor the output power from the VCSEL.

In FIGURE 1, system **10** illustrates one such commercial package. Provided is a TO Can **12**, a sensor **16**, such as a silicon photo-diode, a light source **18**, such as a VCSEL having a gallium arsenide (GaAs) substrate, a beam splitter **20** and a focusing lens **22** which directs a focused light beam **24** to a fiber optic cable **26**. When laser beam **28** impinges upon partial reflector **20**, a monitoring light beam **30**, which is a portion of laser beam **28**, is reflected back to photo-diode **16** to be used to monitor the output power from the VCSEL **18**.

This configuration is not conducive to monitoring of the laser power from the back side of the laser **18**, since the laser is opaque. The one manner in which to attempt to monitor from the backside would be to etch away the substrate at specified areas.

The approach set forth in FIGURE 1 requires the implementation of complicated packaging techniques to align the laser **18**, the photo-diode **16**, the splitter **20** and the fiber **26**. This results in high packaging costs and a higher percentage than desirable of defective systems. It is estimated that when used for transmitters, 90% of the manufacturing cost is directed to the packaging.

Therefore, it has been deemed desirable to find a manner of integrating elements of the system including the VCSELs and photo-diodes as well as potentially optical elements to reduce the packaging costs.

Summary of the Invention

A light-producing and monitoring system includes a device that produces light having wavelengths that can range from approximately 700nm to approximately 3 microns. A semi-transparent sensor is located in front of the light-emitting region, such that at least a portion of the light emitted passes through the semi-transparent sensor and at least a portion of light is absorbed by the semi-transparent sensor. The semi-transparent sensor is configured to be semi-transparent at the wavelength of interest.

Brief description of the Drawings

FIGURE 1 is a VCSEL-based optical transmitter package in accordance with the prior art;

FIGURE 2 sets forth an optical transmitter package wherein a sensor according to the teachings of the present invention is implemented;

FIGURE 3 depicts an optical transmitter package implementing a sensor concept of the present invention and an integrated micro-lens on a single substrate;

FIGURE 4 illustrates a further embodiment of a sensor according to the present invention integrated with a micro-lens on a single substrate;

FIGURES 5a-5d depict one embodiment of constructing a semi-transparent sensor according to the teachings of the present invention;

FIGURES 6a-6d illustrate a top view of the construction in accordance with FIGURES 5a-5d;

FIGURE 7 sets forth a graphical representation of reflectance existing at a 850nm wavelength;

FIGURE 8 depicts representation of a semi-transparent sensor according to the present invention further implementing an anti-reflection layer;

FIGURE 9 is a graphical representation of the reflection occurring in accordance with operation of the sensor described in FIGURE 8;

FIGURE 10 depicts a further embodiment of a anti-reflection coating which may be used with the sensor according to the teachings of the present invention;

FIGURE 11 sets forth a representation of the reflection achieved using the anti-reflection layer of FIGURE 10;

FIGURE 12 is a graphical representation of transmission characteristics for a device configured according to the present invention for operation optimized at 850nm;

FIGURE 13 is a graphical representation of a semi-transparent sensor for operation in accordance with a light-emitting device at 1300nm;

FIGURE 14 sets forth a graphical representation of reflectance occurring in accordance with operation of the sensor described in Figure 13;

FIGURE 15 depicts a more detailed view of one embodiment of an anti-reflection layer described in FIGURE 13;

FIGURE 16 depicts the reflectance using a semi-transparent sensor in accordance with the teachings of FIGURE 15;

FIGURES 17-19 are graphical representations of the optical transmittance versus the light wavelength for devices constructed according to the teachings of the present invention, using different materials and layer thicknesses;

FIGURE 20 illustrates the formation of anti-reflection coatings over both top and bottom surfaces of the sensor;

FIGURES 21a-21b set forth side views of a further embodiment of a sensor according to the teachings of the present invention implementing an absorption layer;

FIGURES 22a-22b depict a top view of FIGURES 21a-21b;

FIGURE 23 illustrates a semi-continuous sensor in connection with the TFT construction;

FIGURE 24 and FIGURE 25 illustrate side and top views of a system using an array of light-emitting devices and a sensor sufficient in size to sense each of these elements;

FIGURE 26 shows a top view of a system using an array of light-emitting devices and a plurality of sensors, each sensor sized to sense a corresponding light-emitting device; and

FIGURE 27 depicts the sensor device of the present invention used between two fiber-optic cables.

Detailed Description of the Preferred Embodiments

As depicted in FIGURE 1 in existing VCSEL-based optical transmitter package **10**, the sensor (i.e. photo-diode **16**) receives the monitoring light signal **30** on the same front surface from which the laser beam **28** is emitted.

Turning to FIGURE 2, illustrated is an optical transmitter system **40** which employs a semi-transparent sensor **42** that is semi-transparent at the wavelengths used for data transmission, in the range of 700 nm - 3 microns. Existing sensor designs did not consider achieving semi-transparency at these wavelengths. It is to be understood that while sensor **42** is noted to be semi-transparent in a range of 700 nm - 3 microns in actual implementation the construction may vary dependent upon the specific wavelengths in this range. The necessary designs for specific wavelengths will be described in greater detail below.

Implementing semi-transparent sensor **42**, within system **40** permits an arrangement where laser **18** is positioned on substrate **14** behind semi-transparent sensor **42**. By inserting semi-transparent sensor **42** within the optical path of beam **46**, the semi-transparent sensor **42** absorbs a small amount of emitted laser beam **46** to be used as a sensor light **48** which provides feedback for control of the VCSEL **18**, which in this embodiment may be a 850nm, 380 x 380μm VCSEL. Laser beam **46** which passes through sensor **16** is focused by micro-lens **22** in order to provide a focused light to fiber optic device **26**. By this design use of partial reflector **20** is not required.

A characteristic of an appropriate semi-transparent sensor is for the sensor to have a high "contrast ratio", also called "light-to-dark" response. Since the sensor will only absorb a fraction of the light passing therethrough, due to its partially transparent nature, it must be able to work even with very small signals. An ideal sensor will have no current flowing when no light exists. Amorphous silicon (a-Si:H) sensors are able to approach this ideal state. Other materials may also be used for the sensor, such as a silicon germanium doped compound.

Turning to FIGURE 3, illustrated is another optical transmission system **50** which implements a semi-transparent sensor **42**. In this embodiment, a VCSEL chip **54** is flip-chip bonded by solder bumps **56** and **58**, to a quartz substrate **60**, aligned to a refractive micro-lens **62** on a second side of quartz substrate **60**. The semi-transparent sensor **42** is

built on a top surface **64** of quartz substrate **60**, inserted in the optical path of laser beam **66**. This design allows sensor **42** to monitor the output power of the VCSEL **54**. Substrate **60** is also chosen to be semi-transparent at the frequency of operation of VCSEL **54**. In this embodiment for example, a quartz substrate may be used and inserted within the optical path for a VCSEL which operates in the range of 700nm-3 microns. Using the transparent structures of quartz substrate **60** and sensor **42**, the total absorption of the system can be controlled to below 10%. It is also to be noted the solder bumps used in the flip-chip technique of the foregoing embodiments, provide an air gap of approximately 50-100 microns which is equivalent to the height of the solder bumps between the substrate and laser.

With attention to FIGURES 2 and 3, it is noted that FIGURE 2 is shown with a lens structure not integrated to the system, and FIGURE 3 illustrates a micro-lens **62** built on top of quartz substrate 60. It is to be appreciated that system **40** of FIGURE 2 may be designed with an integrated micro-lens such as shown in FIGURE 3, and the system **50** of FIGURE 3 may be designed with a non-integrated lens such as shown in FIGURE 2.

It is also to be understood that while FIGURE 3 illustrates the connection between substrate **60** and VCSEL **54** via the use of solder bumps **56** and **58** implementing flip-chip technology, other forms of integrating the components of the systems in FIGURES 2 and 3 may be used. For instance, substrate **60** may be etched with a cavity area into which the laser and other components are held. Other connection techniques may also be used such as the micro-spring techniques of U.S. Serial No. 09/469,122 hereby incorporated by reference.

Turning to FIGURE 4, illustrated is an optical transmitter system **70**, where a VCSEL **54** is integrated with substrate **72** having formed thereon semi-transparent silicon sensor **42** and micro-lens **62**. More particularly, system **70** allows for an integrated transmitter to be packaged in a TO Can. In this embodiment, semi-transparent sensor **52** and micro-lens **62** are integrated on quartz substrate **72** as a sensor chip **74**. Thereafter, sensor chip **74** with the built-in sensor and micro lens is attached to the VCSEL **54**. Such interconnection may be accomplished by many connecting schemes including flip-chip bonding using solder bumps **76** and **78**, as well as other discussed techniques. Though not shown, electrical contacts of the amorphous silicon sensor **42** may be passed on to

wire bonding pads on the top surface of the VCSEL **54**. These wire bonding pads will be isolated from the VCSEL using a dielectric layer. The entire module is then solder bonded to a heat sink in a TO Can.

In certain embodiments, the micro-lens may be eliminated and a discrete lens or collimator can be used outside the TO Can to collimate the light into a multi-mode fiber or other receiving element. In still a further embodiment, substrate **72** is configured as a thin layer which is made part of micro-lens **62**.

When the foregoing system implements a micro-lens, several approaches may be taken including using the quartz substrate. In one embodiment, the micro-lens is fabricated directly out of the quartz substrate by reflowing a polymer micro-lens pattern. The micro-lens is then transferred to the quartz substrate by one of various plasma etching techniques. Also, in addition to refractive micro-lenses, diffractive Fresnel lenses can be used for the focusing of light as well, and the illustrated lens **22,62** are intended to represent all such potential types.

In determining the dimensions of a refractive micro-lens for one embodiment, the diameter will be 100μm and the thickness is 7μm. The focal length of the lens is then calculated to be 300μm. When used in a one-to-one imaging situation from the VCSEL to a multi-mode fiber, the spacing from the VCSEL to the micro-lens will need to be twice that of the focal length, which for a VCSEL operating at 850nm is 600μm. Considering that in one embodiment the divergence of the VCSEL is 10° at FWHM, the spot of the laser beam is approximately 105μm at the surface of the lens which is slightly larger than the diameter of the lens. Since the VCSEL aperture is typically less than 20μm in diameter for a transmitter/transceiver application, and the diameter of a multi-mode fiber is between 50-65μm, the spacing between the VCSEL and the micro-lens can be in the range of 1f and 2f (where f is the focal length), so that the beam spot is magnified at the input of the fiber. By this design, the fiber will not be underfilled.

It is noted that when constructing transmission systems where the micro-lens is integrated, the integration of the optical transmitter can start with the fabrication of the micro-lens on the quartz substrate. Then, taking care not to damage the micro-lens, the amorphous sensor may be fabricated on the opposite side of the quartz substrate with the sensor aligned to the micro-lens. After the sensor has been fabricated, solder bumps may

be formed on the sensor side of the quartz substrate. Thereafter a VCSEL or other light source is attached to the top of the semi-transparent silicon sensor. In this embodiment, solder-wetting metal pads (typically Ti/Au) on the VCSEL match the solder bump array on the quartz substrate. After VCSEL is flip-chipped in place, the assembly is heated above the melting point of the solder (in one embodiment, around 230°C for eutectic PbSn solder). Care should be taken to ensure that the reflow temperature is sufficiently low so as not to damage the sensor. Melted solder bumps reflow and settle into an equilibrium shape and pull the VCSEL into alignment with the sensor and the micro-lens.

Turning attention more particularly to the design of the semi-transparent sensor, attention is directed to FIGURES 5a-d and 6a-d, which are cross-sectional and top views of a process used to form sensor **42** integrated on substrate **16**.

Turning to FIGURES 5a and 6a, illustrated is a first stage of the process flow for the construction of a semi-transparent sensor to be formed on a transparent substrate such as Corning 1737 glass **90**, fused silica ,quartz or silicon at longer wavelengths. This embodiment will set forth configurations for a sensor which will be semi-transparent in the 850nm light wavelength range. In the first stage a transparent/conductive layer **92**, such as indium tin oxide (ITO), tin oxide, zinc oxide, polycrystalline silicon or other appropriate material is patterned in accordance with known techniques. Transparent/conductive layer **92** needs to be transparent such that it does not block light emitted from lasers **12** in the 850nm wavelength range, and is required to be conductive as it will act as a first electrode of the sensor. To meet these requirements, ITO layer **42** is selected to be approximately 55 nm thick.

Turning to stage 2, illustrated by FIGURES 5b and 6b, a hydrogenated amorphous silicon sensor (a-Si:H) component or active sensor element **94** is grown on top of the first transparent/conductive layer **92**. Active sensor element **94** is shown comprised of three sub-layers. The first sub-layer **94a**, is a n^+-doped layer of material, typically less than 1,000 angstroms in thickness and more preferably 50 nm thick. Though not limited thereto, first sub-layer **94a** may be a n^+ phosphorous-doped amorphous silicon, or n^+ arsenic-doped silicon. A second sub-layer **94b** is intrinsic amorphous silicon, of a thickness less than a micron, in the range of 1μm thick. The third sub-layer **94c** of sensor element **94** is a p^+doped amorphous silicon approximately 50 nm thick. An example of a

p^+-doped amorphous silicon which may be used as third layer **94c** is p^+ boron-doped amorphous silicon. The amorphous sensor active component **94** may also be made of hydrogenated amorphous silicon-germanium compound (a-SiGe:H).

Following deposition of active sensor element **94**, a second transparent/conductive layer **96** is deposited on top of sensor element **94**. Sensor element **94** and second transparent/conductive layer **96** may be patterned together in a single process or separately. Layer **96** in this embodiment may be the same material as layer **92**, such as a layer of ITO, tin oxide, zinc oxide, Polycrystalline silicon or other appropriate material having a thickness of approximately 55 nm. By this design, active sensor element **94** in the present embodiment is an amorphous silicon sensor, which is opaque in visible light, and substantially transparent at an IR wavelength at and around 850nm.

Turning to stage 3 of the process, shown in FIGURES 5c and 6c, passivation layer **98** is deposited. Passivation layer **98** may be amorphous silicon-nitride (SiNx), oxynitride, or polyamide among other possible choices. Layer **98** acts as a passivation layer for the sensor by being electrically insulating and, is also formed to be transparent in the wavelength range emitted by the lasers associated with the sensor. In this embodiment, therefore passivation layer **98** is made in a thickness of about 3,000nm

Two vias are provided through passivation layer **98** to allow contact to transparent/conductive layers **92** and **96**. First via **100** and second via **102** may be seen clearly in top view FIGURE 6c. The first via **100** provides an opening to second transparent/conductive layer **96** and second via **102** provides an opening to first transparent/conductive layer **92**. These openings are used to provide access to layers **92, 96** since the passivation layer **98** is formed from an electrically insulating material and, since layers **92** and **96** act as electrodes of the sensor.

At this point, an electrically protected semi-transparent sensor **104** is formed which is semi-transparent in the 850nm wavelength range. Again, the sensor consists of first transparent/conductive layer **92**, sensor element **94**, second transparent/conductive layer **96** passivation layer **98**, and vias **100, 102** which provide electrical access to sensor **104.**

Attention is now directed to a stage 4 which may be undertaken and is illustrated in FIGURES 5d and 6d. In this stage, metal patterns **106** and **108** are deposited directly

onto passivation layer **98** and into vias **100** and **102**. Metal patterns **106**, and **108**, may be deposited during the same processing steps.

In one preferred embodiment, metal patterns **106** and **108** are made a highly conductive material such as gold or other appropriate material. Depositing of the metal patterns **106** and **108** may be achieved by many methods including electron-beam deposition, thermal evaporation, chemical vapor deposition, sputter deposition or other methods.

After metal layers for patterns **106** and **108** have been deposited, they are patterned by photolithography into desired designs. Metal patterns **106, 108** are used as sensor readout lines and contact elements to the first transparent/conductive layer **92** and second transparent/conductive layer **96**, which act as electrodes for sensor **104**.

Light being directed to sensor **104** may either be absorbed, transmitted, or reflected. Reflection of light is undesirable as compared to the other possibilities, since if light is absorbed, the sensor is using it to determine an appropriate feedback to the system, and if light passes through, it is being used by the target device, for instance to transmit voice, data, or video data in a communication transmission system, create a latent image on an electrostatic drum or for other useful purposes. On the other hand, reflected light is wasted light.

FIGURE 7 is a graphical representation of the reflectivity of a sensor as configured in accordance with FIGURES 5a-d and 6a-d when operated with a laser at 850nm. As can be seen, reflectivity is equal to 10% at the 850nm wavelength. This means that a percentage of laser light is lost and unusable. In order to improve this situation, the present embodiment adds a further layer to the sensor described in connection with FIGURES 5a-d and 6a-d.

Particularly, an impedance-matching layer **110**, as shown in FIGURE 8 is patterned on top of the ITO layer **96**. Layer **110** is an anti-reflection coating and in one embodiment may be a layer of silicon dioxide of 73.8nm thick. This thickness is used to match the wavelength of 850nm assumed in the present embodiment. It is to be appreciated that while silicon dioxide is in one embodiment used as the anti-reflection layer **110**, other anti-reflection coatings including silicon nitride or other dielectrics with a proper refractive index and proper thickness may be implemented.

The addition of layer **110** minimizes the reflection loss, as evidenced in FIGURE 9. More specifically, when implementing anti-reflection layer **110**, the reflection loss at approximately 850nm is reduced to 0.4%.

A further embodiment of anti-reflection layer **110** is shown for example in FIGURE 10. In this figure, the layer includes three sub-layers including a 122.8nm sub-layer of magnesium-oxide **113a**, a 132nm sub-layer of cerium-fluoride **113b**, and a 82.6nm sub-layer of silicon-dioxide **113c**. The more sophisticated anti-reflection layer **112** of FIGURE 10 further minimizes reflection loss as shown by the graph of FIGURE 11, where the reflection loss is shown to be approximately 0.03% at 850nm.

In yet another embodiment, a sensor according to the present invention such as taught for example in the forgoing figures, may be implemented with a first layer of TiO2 87.20nm thick, an ITO electrode layer 10nm thick, an amorphous silicon sensor region of 707.68nm, a second indium tin-oxide (ITO) electrode 20nm thick, a layer of titanium-oxide (TiO2) having a thickness of 93.46nm, and a silicon-oxide (SiO2) layer having a thickness of 225.5nm. This embodiment features a dielectric layer beneath the first electrode **92** and has a large transmission bandwidth that allows operation at a wide range of wavelengths.

Turning attention to FIGURE 12, provided is a graph of light transmittance versus light wavelength (nm) for a device configured using the above materials in the recited thicknesses. As may be observed in this graphical representation, the highest percentage of light passage is at approximately the 850nm wavelength, where light transmittance reaches nearly 98 percent.

Turning to FIGURE 13, shown is an embodiment of an amorphous silicon sensor **120** whose layers and thickness have been optimized for low reflection when used with a light-emitting device such as a laser generating a wavelength in the range of 1.1 to 1.4 microns and preferably at 1.3 microns. Optical transmitters/transceivers operating in this range are commonly used in the telecommunication industry.

This embodiment contains similar process techniques as that shown in FIGURES 5a-d and 6a-d and similar layers will be commonly numbered. For example, the transparent substrate **40** may be the same thickness as that of FIGURES 5 and 6 and may also be, but is not limited thereto, a Corning 1737 glass, fused silica or quartz . Layer

122 is a transparent electrode such as an ITO. However, the thickness of this ITO or other appropriate material will preferably be approximately 48.7nm. Similar to the layer **42** of FIGURES 5 and 6, this electrode may be comprised of other materials such as zinc-oxide or polycrystalline silicon.

Active sensor portion **124** includes a n+ doped silicon photo-detector sub-layer (e.g. n+ phosphorus-doped amorphous silicon, or n+ arsenic-doped silicon, or other appropriate material) **124a** having a thickness of about 50 nm. A second sub-layer **124b** may be an intrinsic amorphous silicon having a thickness of 1.189μm, and a third layer **124c** may be a p+ doped amorphous silicon having a thickness of about 50 nm. Other materials which may be used in the configuration of the sensor include Ge alloys of a-Si.

Formed on top of portion **124** is a second transparent electrode **126** such as an ITO having a thickness of approximately 48.7nm. Another possibility for this electrode includes zinc-oxide, polycrystalline silicon or other appropriate conductive material. An impedance-matching layer **128**, of an appropriate thickness and refractive index, is then laid on top of layer **126**.

As can be seen in FIGURE 14, a sensor configured according to the teachings of FIGURE 13, without a sensor-matching layer **128**, will have a reflectivity loss of 8.1% at a laser light output wavelength of approximately 1300nm.

When an anti-reflection layer **129**having a 189nm layer of magnesium-oxide, a 203.1nm layer of cerium-fluoride, and a 108.3nm layer of silicon-dioxide as shown in FIGURE 15, is placed above the upper electrode , then as shown in FIGURE 16, the reflection losses drop to 0.09% at about 1300nm.

In another embodiment, an amorphous silicon sensor such as **120** of FIGURE 13 has the thicknesses of its layers altered to be advantageously used with light-emitting lasers functioning in the wavelengths in the range of 1.4 - 1.6 microns, and preferably 1.5 microns. This range of wavelengths are commonly used in the telecommunication industry.

When designing semi-transparent sensors for long wavelength operation (greater than 1.3 microns), particular attention should be made on the selection of electrode material as ITO becomes increasingly absorptive at long wavelengths. If ITO is used, its thickness, oxygen content and position relative to the other layers should be optimized

using standard optical modeling and process development techniques to reduce insertion loss.

FIGURE 17 shows a graph of light transmittance versus light wavelength (nm) for a specific design which may be implemented in accordance with the teachings of this application. More specifically, the operational characteristics shown in FIGURE 17 are for a device with a layer of silicon having a thickness of approximately 35.48nm deposited on a glass substrate. A SiO_2 layer having a thickness of approximately 86.68 nm is positioned above this silicon layer. A second silicon layer having a thickness of approximately 141.84nm is then placed above the SiO_2 layer. A lower ITO electrode having a thickness of approximately 10 nm is placed next, upon which is positioned an amorphous silicon (Si) sensor region approximately 663 nm thick, followed by an upper ITO electrode having a thickness of approximately 20 nm thick. Above the upper ITO electrode is placed another silicon layer having a thickness of approximately 68.10nm, and a final SiO_2 top layer of approximately 274.59nm thick.

Such a design, as shown by the graph of FIGURE 17, produces a generally high level of transmittance of approximately 95% of light at the 1500nm wavelength. Unlike more conventional anti-reflection designs, this embodiment features several dielectric layers below the first electrode. The design produces a large transmission window that allows operation at a wide range of wavelengths. This wide transmission bandwidth is especially useful in optical communication applications utilizing wavelength division multiplexing.

Turning to FIGURE 18, illustrated is a graphical representation for a further device according to the present invention which is intended to have a high transmittance at 1500nm. It is noted that this device includes a first TiO_2 layer of 158.13 nm, a first ITO layer of 10nm, upon which is placed a Si layer of 601.47nm. Thereafter, located on top of the silicon layer is a second ITO layer of 20nm, a TiO_2 layer of 102.26nm, and finally a SiO_2 layer of 154.79nm. For this design, the light transmission at 1500 nm wavelength is slightly below 95%.

Comparing the design of FIGURE 17 with the design of FIGURE 18, it is noted that the design of FIGURE 18 has an advantage of fewer deposition cycles, as the TiO_2 and the SiO_2 may be deposited in the same batch as the ITO. However, when using this

design, there is concern with the manner in which the photovolatic Si layers will grow on the TiO2.

A third representation for a sensor according to the present invention and the transmission of light through such a sensor is shown in FIGURE 19. In this design, a first layer of TiO2 is used having a thickness of approximately 158.34 nm. Deposited on top of this is a first ITO layer of 5 nm, on which is located a Si sensor region of 568.97 nm. Deposited on top of the Si layer is a second ITO layer of approximately 10 nm. Next is a layer of TiO2 of approximately 106.89 nm thick, and thereafter a layer of SiO2 181.15 nm thick is deposited.

As illustrated by the graphical representation in FIGURE 19, it is noted the transmittance percentage of light at the 1500nm wavelength is approximately 97%.

From the forgoing designs and the graphical representations of the outputs in FIGURES 17 through 19 of these designs, it may be seen that improvements may be achieved in the percentage of light transmitted. However, improving the output does include at times more complicated deposition processes. For example, in the last mentioned design as reflected by FIGURE 19, the improvement is achieved, however it is necessary to use extremely thin layers of the ITO.

Turning to FIGURE 20, each of the sensors of the foregoing descriptions may take advantage of an additional anti-reflective coating on the device backside. More particularly, a sensor **130** formed of amorphous silicon or other appropriate material has patterned on its upper surface a distributed bragg reflector **132** A second distributed bragg reflector **134** is configured below the sensor **130**, creating a Fabry Perot cavity. Formation of this cavity allows for the creation of an electric field standing wave profile. The standing wave profile is then designed to have a low amplitude at the electrode region which in turn minimizes absorption losses at the electrode. Careful attention needs to be placed in optimizing the tradeoff between minimizing absorption in the ITO and maximizing transmission through the layer stack. It is to be understood that this feature and concept may be applied to all embodiments previously described.

Turning to FIGURES 21a-b and 22a-b, another embodiment of the present invention is illustrated. When operated below its threshold conditions, a laser will emit light through a process known as spontaneous emission. This spontaneous emission may

contain light in the visible wavelength range that is highly absorbed by the sensor material. It is undesirable to have this light, as well as light of any other undesired wavelength, reaching the active sensor element **94**. Therefore, to further improve the operation of the present invention, when IR lasers are used, an additional processing step may be added. Particularly, after the application of second transparent/conductive layer **96** (as depicted in FIGURE 5b), a visible light absorption filter **140**, which may be hydrogenated amorphous silicon (a-Si:H), is deposited on top of second transparent/conductive layer **96** prior to sensor element **94** and second transparent/conductive layer **96** being patterned. Visible light absorption layer **140** is opaque to visible light, and transparent to IR light. Once sensor element **94**, second transparent/conductive layer **96** and visible light absorption layer **140** have been deposited on top of first transparent/conductive layer **92**, they are patterned. Next, and similar to FIGURE 5c, passivation layer **98** is deposited over this patterned stack, and over transparent/conductive layer **92** and substrate **90**. Thereafter, and as shown in FIGURES 21a and 22a, vias **142** and **143** are provided through passivation layer **98** and visible light absorption layer **140**, to provide access to transparent/conductive layers **96** and **92**. By this design, an electrically isolated sensor **144** is formed. The anti-reflection coating needs to be modified as appropriate.

As depicted in FIGURES 21b and 22b, metal layers **145** and **148** are deposited in a manner similar to that discussed in relationship to FIGURES 5d and 6d.

The embodiment shown in FIGURES 21a-21b and 22a-22b adds visible light absorption layer **140**, which provides a manner of preventing spontaneously emitted visible light from impinging upon active sensor element **94**. This avoids false readings from sensor **144**.

When the laser goes above the laser threshold, spontaneous emissions may still exist, too. An ideal sensor is "blind" to the spontaneous emission component, i.e. it has a very narrow bandwidth. Therefore it reads nothing but the resonant component of the laser operation. Absorption layer **140** is able to absorb the continuing spontaneous emissions, so that it does not reach sensor element **94**.

When a semi-transparent sensor is configured for use with a light-emitting device which emits a light in the wavelengths starting at approximately 1.3 microns and above,

consideration must be given to the formation of electrodes which, in one example is configured of indium-tin oxide (ITO). Specifically ITO electrodes become absorbing in the range of 1.3 microns and above. In consideration of this, ITO material for such use must be designed to be less absorbent. To achieve this, the ITO is formed to contain more oxygen than ITO films used in systems which employ wavelengths below 1.3 microns. Using ITO with an increased level of oxygen, permits for a more transparent film for use on the sensor. However, a tradeoff in obtaining this higher transparency is an increase in the resistance of the film. Therefore, consideration needs to be taken as to the tradeoff between resistance and transparency dependent upon the particular implementation. For shorter wavelengths such as 850nm, the ITO electrode would be configured to have transparency, and have as much conductivity as possible. An ITO electrode for systems operating at approximately 1.1 - 1.7 micron wavelengths will differ in composition and thickness from that of a sensor to be used in connection with a laser producing 850nm wavelength beams.

Turning to FIGURE 23, the cross section of an integrated device **160** is illustrated having a transistor, e.g. Thin-Film Transistor (TFT) switch **162** configured below a semi-continuous sensor **164**. In this embodiment, p-i-n-amorphous silicon (a-Si:H) sensor **104** of FIGURES 5b and 6b is replaced by a more elaborate composition. The combination of TFT switch **162** and semi-continuous sensor **164** are meant to be shown as a pixel, or picture element of a 1- or 2-dimensional array, enclosed in a layer of passivation, for operation as an active matrix sensor.

With more particular attention to the construction of device **160**, deposited on a transparent substrate **170** such as glass, is a gate contact **172** formed of a transparent metal, such as Chromium (Cr). Metal layer **172** is deposited in a thickness of approximately 3,000 angstroms, and acts as the gate contact of TFT switch **162**. Deposited over metal portion **172**, and remaining portions of substrate **170**, is a first transparent/conductive layer **174**, such as nitride, oxynitride, polyamide or other appropriate material, which is typically deposited to approximately 3,000 angstroms in thickness. Deposited over layer **174** is a layer **176** of an intrinsic hydrogenated amorphous silicon (a-Si:H), typically 500 angstroms thick.

An island of nitride (oxynitride, polyamide, etc.) **178** is deposited and patterned over gate contact **172** on the a-Si:H layer **176**. Island **178** is typically deposited to a thickness of approximately 2,000 angstroms.

A layer of n-doped a-Si:H **180** is then deposited and selectively patterned to a thickness of approximately 1,000 angstroms over nitride island **178** and layer **176**.

Next, a layer of transparent conductor **182** is deposited on top of island **178**, and an opening **184** is patterned to create two electrodes **182a, 182b** from layer **180**. The metal of layer **182** may typically be configured of Indium Tin Oxide (ITO) . Patterns **182a** and **182b** act as the source and drain contacts for TFT transistor **162**. A passivation layer **186** is patterned on top of conductor layer **182** and may typically be oxynitride of approximately 1 micron, or alternatively a polyamide layer of approximately 2.3 microns thickness. A via in layer **186** is opened, such that a transparent/conductive layer **188**, typically made of ITO, and an n^+-doped amorphous silicon layer **190,** are deposited and patterned in a mushroom-shape inside and over the via. Layer **188** functions as the bottom electrode of sensor **164.** Layer **188** is deposited such that, in the via, it is in contact with layer **182** and over remaining portions of layer **186**. The n^+-doped contact layer **190** is typically 700 angstroms thick.

A continuous layer of intrinsic amorphous silicon (a-Si:H) **192** is deposited over the n^+-doped contact **188** and portions of the passivation layer **186**. This layer of sensor **164** has a typical thickness of approximately 1 micron.

A p^+-doped layer **194** is then deposited over intrinsic a-Si layer **192** to a thickness of approximately 100 angstroms. A transparent/conductive layer **196,** typically made of ITO and 5,500 angstroms thick, acts as a top electrode of sensor **164**. Thereafter, a top passivation layer **198** is deposited and patterned.

This embodiment of device **160**, therefore, consists of a TFT transistor **162** which is connected to the semi-continuous sensor **164** through the opening created in passivation layer **186**. The sensor **164** is otherwise separated from the TFT on a top level by portions of passivation layer **186** that have not been etched away. It is to be appreciated that the described semi-continuous sensor **164** may be constructed using the materials and thickness described above, for operation with specific light wavelengths in the range of 700nm - 3 microns.

In the foregoing embodiments, discussion has been generally directed to a sensor sensing a single laser output. However, in many instances, the sensor will be defined for use with an array of lasers such as used on an image print bar.

In a typical print bar arrangement, a large number of individual light-emitting sources such as lasers, LED or other light sources are arranged in an elongated, planer array that is placed adjacent an image recording member. By providing relative motion between the print bar and the image recording member, the print bar scans the image recording member, and by selectively illuminating the individual light-emitting sources, a desired light image is recorded on the image recording member.

Turning to FIGURE 24, shown is a cross-section of a print bar/sensor system **200** employing the concepts of the present invention. In one embodiment, system **200** includes an array of lasers **202**, a first driver chip **204** and a second driver chip **206**. Each of driver chips **204** and **206** can control operation of lines from one side of the array of lasers **202**. Connection between driver chips **204** and **206** and the array of lasers **202** is achieved by connection to substrate **208** via flip-chip technology implementing solder connections such as solder balls **210**. Substrate **208** carries electrical tracings **212** permitting connection between laser array **202** and controller chips **204** and **206**. Semi-transparent sensor **214** senses a portion of emitted light **216** to assist in the calibration of laser array **202**. Particularly, it is noted that substrate **208** as well as sensor **214** are transparent and laser beam (IR radiation) **216** is capable of passing substantially unobstructed through substrate **208** and sensor **214**. By forming sensor **214** in a fashion which allows it to be aligned with a high degree of precision in front of laser array **202**, it is possible to obtain in situ information as to laser output for each of lasers of the laser array **202**.

FIGURE 25 depicts a bottom view of FIGURE 24. Sensor **202**, solder balls **210** and electrical tracings **212** are on substantially the same plane nearest the page surface, and laser array **202** is on the back of the page. Contact pads **216** and electrical tracings **212** are provided for connection to chips **204** and **206** respectively. FIGURE 25 emphasizes the importance of alignment between sensor **214** and the array of lasers **202**, in that sensor **214** is sufficiently sized to cover all lasers **202** in this embodiment. Sensor feedback lines **218** are shown extending from sensor **214**. Sensor feedback lines **218** are

capable of carrying readout current used for various purposes including calibration operations. FIGURE 25 emphasizes the importance of alignment between sensor **214** and the array of lasers **202**, in that sensor **214** is sufficiently sized to cover all lasers of the array **202**.

Turning to FIGURE 26, shown is a top view of a further embodiment of a light-emitting/sensor arrangement **221.** FIGURE 26 highlights the relationship between the light-emitting array **202** (such as shown in FIGURE 24) and distinct sensors **222** individually aligned to lasers of the array **202**. Contact pads **224** and electrical tracings **226** provide the connection to components such as chips **204** and **206** of FIGURE 24.

With further attention to FIGURE 26, sensor feedback lines **228** are provided for each individual sensor **222** and are illustrated extending from the sensors. Sensor feedback lines **228** are capable of carrying readout current used for various purposes including calibration operations. FIGURE 26 emphasizes the importance of alignment between the sensors **222** and the array of lasers **202**, and that the sensors **222** may be individually sized and correlated to specific lasers of the array.

The foregoing described systems **200** and **221** emphasize arrangements which allow for calibration of lasers. Such a calibration system is described more fully in the hereby incorporated U.S. Serial No. 09/469,122, and its disclosure is equally applicable to use with the presently described laser-emitting devices and sensors.

It is also to be appreciated that use of the present invention with light emitting arrays other than for use with print bars is equally applicable. For example, such other use maybe in connection with communication in the telecommunication industry and other industries. FIGURES 24 and 25 do not illustrate lenses to focus the output light, either as elements separate from the substrate, or integrated therein on its backside. Such arrangements are also possible using the array of lasers and the sensor of the present invention.

Turning to FIGURE 27, a further embodiment of the present invention is illustrated. More particularly, a light sensor configuration **230** as previously described is inserted within the path of an optical fiber **232** which transmits a light signal generated by a light source **233** and passes that signal to another optical light fiber **234**. It is noted that light source **233** may be located off-site or far away from light sensor configuration **230**.

The semi-transparent sensor **236** is located on a first surface of substrate **238** and a focusing element **240** such as a lens is on the opposite surface. This embodiment illustrates that the present invention may be used in a situation where the light to be sensed is not generated by use of a light source located on site, but rather is produced from an off-site source and is transmitted to sensor configuration **230**. In this embodiment sensor configuration **230** acts as an optical coupler, to bring two optical fibers together. Use of the present invention allows for sensing of a portion of the light being passed, by sensor **236**, in order to monitor the amount of light or to note if a link failure or other form of failure exists in the connection. While the embodiment of FIGURE 27 shows the lens **240** integrated to substrate **238**. It is to be appreciated that a separate non-integrated lens may be used, or no lens may be used. Further, the light focusing element **240** may also be a collimator. In this embodiment configuration **230** is used to sense and collimate a diverging light from optical fiber **232**. As mentioned previously, a collimator may also be used in connection with a single light source such as those described above.

The foregoing is considered as illustrative only of the principles of the invention. Further, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation as shown and described, and accordingly, all suitable modifications and equivalents may be resorted to falling within the scope of the invention.

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